Graphene Synthesis

I. Challenges

1. Cost "€/cm^2"

2010	2013	2022
1000	10	0.01

2. Handling

- The world's thinnest material.
- Extremely difficult to handle.
- Supported by:
  - Substrate
  - Dispersed as flakes in a solvent.

3. Wafer Scale

- Graphene needs to be grown on suitable wafer scales.

4. Band Gap

- Electronic Devices require semiconductor with band gap.
- Graphene has no band gap.
- Inducing band gap in graphene is an active research area.

5. Encapsulation

- Graphene is highly susceptible to environmental influences.

II. Synthesis methods

1. Exfoliation

a. Scotch Tape
b. Etched Silicon

2. Chemical Growth

a. Graphene Oxide Reduction
b. Epitaxial Growth
   i. Heating
   ii. Molecular Beam

3. Chemical Vapor Deposition

1. Exfoliation

a. Scotch Tape

1. Scotch tape on graphite
2. Folding tape repeatedly
3. Attach tape to substrate
4. Remove tape
5. Optical Microscope to examine graphene flakes.

b. Etched Silicon

1. Pure graphite attached to toothpick.
2. Prepare Silicon wafer with 0.25 micron silicon dioxide layer.
3. Radio frequency plasma etching used to create trenches.
4. Drag graphite across the trenches
5. The trenches will pull-off pieces of graphite creating graphene.

2. Chemical Growth

a. Graphene Oxide Reduction

- Intersection of exfoliation and chemical growth methods.

1. Exfoliated graphene flakes are oxidized.
2. Suspension in aqueous solution.
3. Passed through a filter membrane with pores around 25 nanometers.
4. Covering whole membrane with graphene oxide flakes.

b. Epitaxial Growth

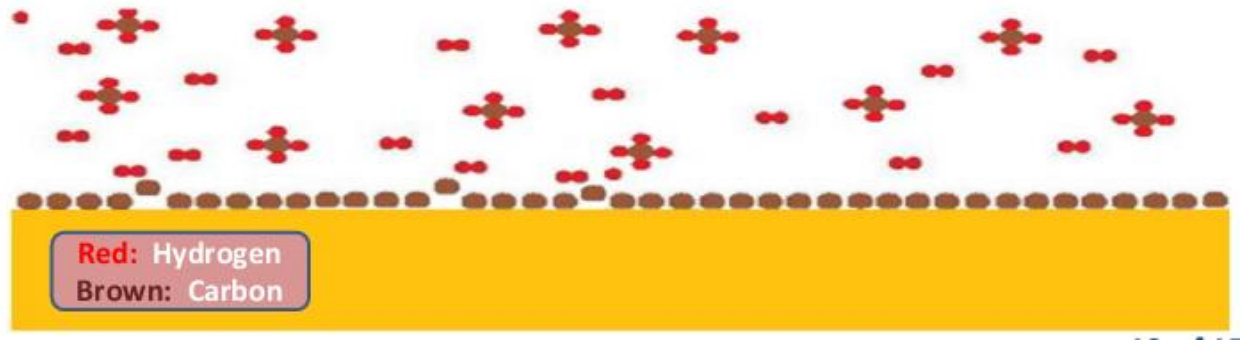
1. Heating

1. High quality monolayer graphene.
2. Grown from silicon carbide (SiC).
3. Bulk SiC is heated to around 1500°C.
4. Layer of Graphene forms on the surface.

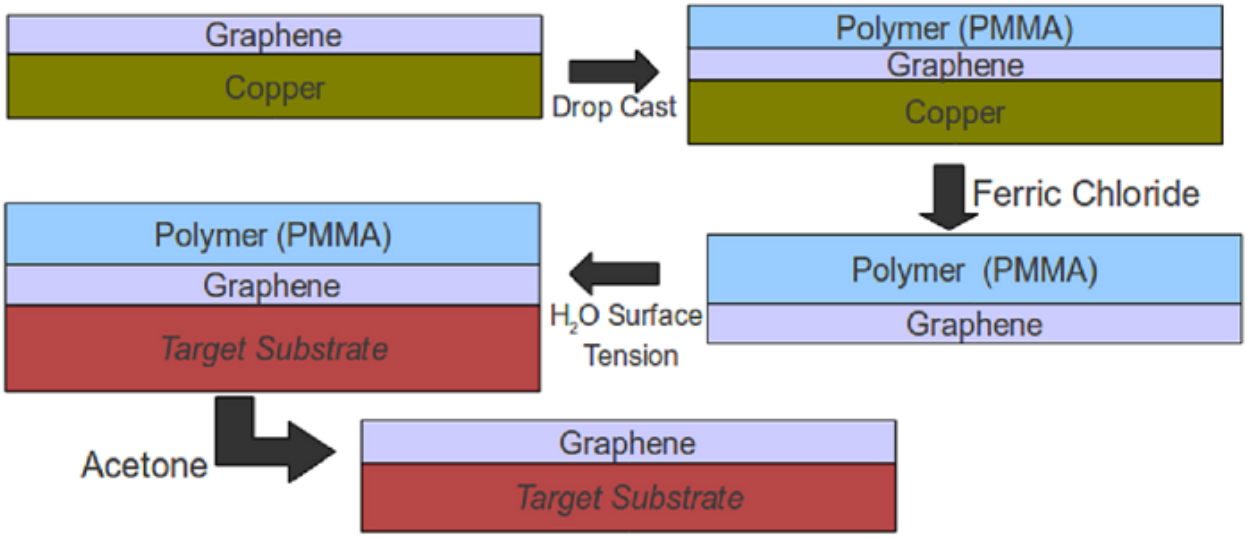
2. Molecular Beam

1. A graphite filament is loaded into an ultra-high vacuum.
2. Filament is heated, carbon atoms sublimate off of the graphite.
3. Carbons form a molecular beam in the vacuum
4. Travel Space until it lands on metal substrate like iridium

3. **Chemical Vapor Deposition**
    1. Metal substrate is put into low Vacuum furnace at 1000°C.
    2. Methane and hydrogen gases are flowed through the furnace.
    3. Hydrogen catalyzes reaction between methane and metal substrate.
    4. Carbon atoms from methane absorbed onto the surface of substrate.
    5. Furnace is quickly cooled to prevent formation of graphite.



III. Graphene Transfer Process



IV. Conclusion

Chemical Reduction and CVD are the most common Graphene synthesis techniques as they can produce larger graphene sheets than exfoliation which can only produce graphene flaks suitable for laboratory purposes.